A ZVS Single Stage High Voltage Gain Boost Converter Feasible to pv Battery Charger Systems

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Abstract— **This paper presents a soft-switching (ZVS) boost converter integrated in such a way to obtain, in a single conversion stage, the maximum energy extraction from photovoltaic panels, battery charging and discharging dynamic control, and high voltage step-up to the inverter DC bus, also operating with soft-switching capability. In order to verify its effectiveness, simulation results from this converter are presented. Theoretical analysis, operation principle and topology details are also presented and studied. High voltage gain, low switching stress, small switching losses, and high efficiency are expected from this topology.**

Keywords—Converters, Photovoltaic Panel, ZVS.

I.INTRODUCTION

Renewable energy systems using, as main energy source, photovoltaic panels and/or fuel cells have an intrinsic characteristic of producing low voltage levels, requiring a DC converter with large voltage step-up in order to produce a high voltage DC bus which feeds an DC AC converter.

Though conventional boost converter can theoretically be used for this purpose, obtaining such high voltage gain implies that it would operate with duty cycles greater than0.9, which is not feasible due to the great variations on the output voltage caused by small variations on the duty cycle, leading the boost converter to instability.

To overcome this drawback, a large number of large voltage step-up converters have been proposed. In [3] and [4], the use of an interleaved boost converter associated with an isolated transformer was introduced, using a high frequency AC link. Despite of the good performance, this topology uses three magnetic cores. In [5], the converter presents low input current ripple and low voltage stress across the switches. However, high current flows through the series capacitors at high power levels. In [6-8], converters with high static gain based on the boost-flyback topology are introduced, which presents low voltage stress across the switches, but the input current is pulsed, as it needs an LC input filter.

The step-up switching-mode converter with high voltage gain using a switched-capacitor circuit was proposed in [9]. This idea is only adequate for low power converters as it results in a high voltage stress across the switches and many capacitors are necessary. In [10-12] the three-state switching cell is shown. In [12] a voltage doubler rectifier is employed as the output stage of an interleaved boost converter with coupled inductors[13] the converter has some advantages compared tothe others: possibility to operate in large voltage range, high efficiency, and high power capability. It can be seen in [13] that the number of semiconductor devices is the same as in the traditional interleaved boost arrangement, though two coupled inductors L1 and L2 are added, resulting in higher output voltage. The main drawback of this topology is the hard switching mode, which causes power losses.

The structure presented in [14] is an alternative of [13], in which a commutation cell is associated to the main topology in order to reduce the current stress on the switches. Despite of achieving higher efficiency, this solution leads to a more complex control and structure, due to the presence of an extra auxiliary circuit for each switch. Nevertheless, most of solutions include different stages to perform battery charging and step up goals.

This paper presents a new high voltage gain DC/DC converter, as can be seen in Figure 1. The main advantage of the proposed structure is the low voltage stress across the switches, which is naturally achieved by the converter characteristic, without the need of inserting an extra auxiliary circuit for achieving ZVS operation. A single-stage converter with high step-up gain then results, while an integrated system with battery charging from a photovoltaic panel is also obtained. The duty cycle allows the MPPT control and the battery absorbs or delivery energy automatically according to the load condition and maintaining acceptable output voltage regulation.

Within this context, this paper proposes the integration of the battery charger stage, the photovoltaic power stage

and the high voltage step-up stage in a single-stage power converter. From this new concept, many high step-up voltage power converters can be obtained resulting in new topologies with all aforementioned characteristics.

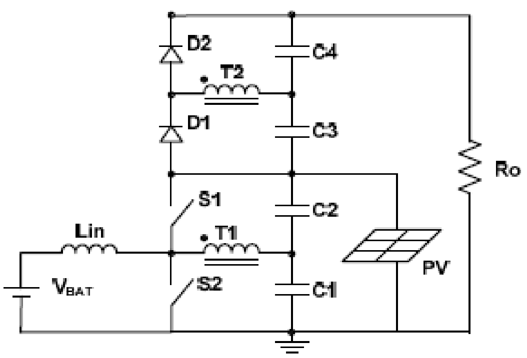

Fig. 1. Proposed topology using a PV system.

II. CONCEPTION OF TOPOLOGY

Some high voltage gain topologies have three dc links as shown in Fig. 2, where VDC3 feeds the inverter with a higher voltage than that of the remaining ones. According to the proposal, the battery bank and the photovoltaic panel can be connected to the low voltage VDC1 or VDC2, depending on the available voltage levels. Considering typical applications under 2kW, battery banks voltage levels can be 12V, 24V or 48V (in order to avoid the connection of many units in series) and photovoltaic panels can be arranged to establish a dc link with voltage level equal to about twice that of the former link.

The bidirectional characteristic of the half-bridge topology allows either charging the battery from the PV array or feeding VDC3. Besides, the use of resonant capacitors in the half-bridge capacitors allows soft switching (ZVS or ZCS) of the switches. The integrated topology resulting from the boost half bridge is then shown in Fig. 1. The main advantage of this topology is the low voltage stress across the active switches, low input current ripple and simplicity, what results in higher efficiency.

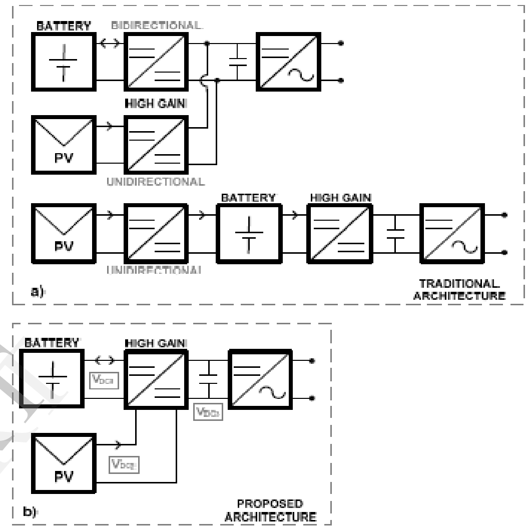

Fig. 2. a) Conventional Architecture b) Proposed Architecture

III. STATIC GAIN

The output voltage at any given moment can be expressed as the sum of the voltages across each output capacitor, C1, C2, C3 e C4, as presented in equation (1).

$$Vo = V_{c1} + V_{c2} + V_{c3} + V_{c4} \quad (1)$$

Relation (2) can be obtained observing that the voltage across the inductors Lr1 and Lr2 must be null during a switching cycle period, the voltage across the capacitor VC2 can be expressed by (2).

$$V_{c2} = \underline{DVin} \quad (2)$$

1 – D

Due to the transformer relation (n), it must be noticed that the voltage across C1are related to the voltage across C3 according 4 and.

$$V_{c1} = Vin \quad (3)$$

$$V_{c3} = nVin \quad (4)$$

Similarly to the condition presented on equation (3), the voltage across C4 has a direct relation to the voltage across C2 and the transformer relation (n), as shown in (6).

$$V_{c4} = \frac{n\,DVin}{1-D} \quad (6)$$

Substituting (3)-(6) in (1), it can be determined the static gain, as shown in equation (7).

$$G = \frac{Vo}{Vin} = \frac{1+n}{1-D} \quad (7)$$

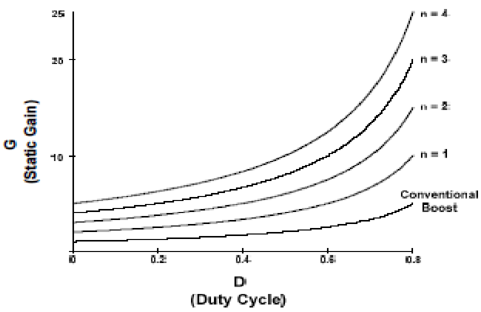

Fig. 3. Relation G x D for different values of 'n'.

Figure 3 presents the curves relating the static gain (G) with the duty cycle (D) for different values of n.

IV. OPERATION PRINCIPLE

This section presents the operation principle from the high voltage gain boost converter. For the theoretical analysis, it will be considered that the input voltage (Vin) and output current (Io) are ripple free and all devices are ideal. From Figure 4, it can be observed the main theoretical waveforms, which illustrate the details of the operation principle stages explained above.

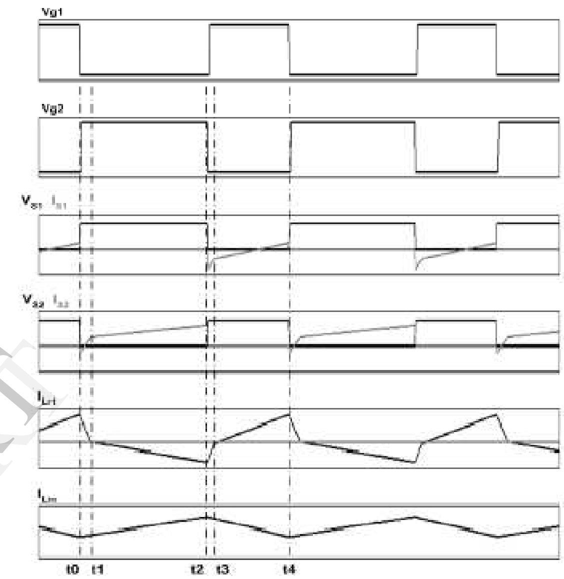

Fig. 4. Main theoretical waveforms.

First Stage [t0 – t1] - At t0, S1 is turned-off and S2 is maintained turned-on, as presented in Figure 5. On this stage, the difference between the conduced current due to the transformer leakage and the input current flows through the anti-parallel diode of S2 and decreases linearly. This stage ends when the current on the primary side of the transformer is zero.

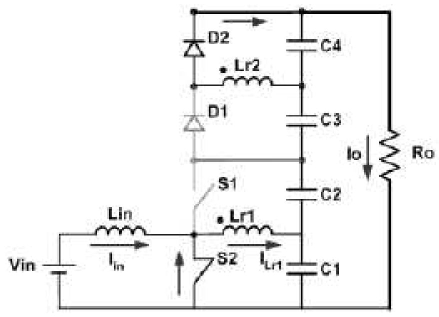

Fig. 5. First Stage.

Second Stage [t1 – t2] – On this stage, the current through the primary side is added to the input current and conducted through the switch S2. The secondary circuit charges the capacitor C3 through diode D1.

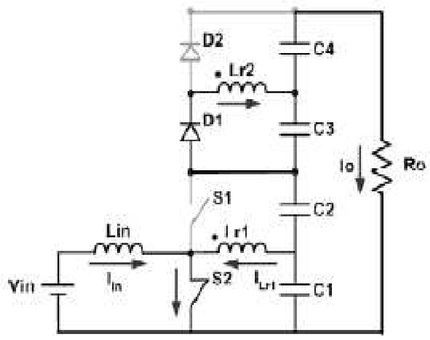

Fig. 6. Second Stage.

Third Stage [t2 – t3] – This stage begins when S2 turns off and S1 turns-on. The current that flows through S1 is the sum of the input current and the one through the transformer primary side, and increases linearly. This stage ends when the current on the primary reaches zero.

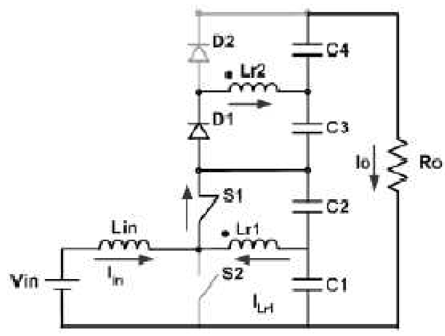

Fig. 7. Third Stage.

Fourth Stage [t3 – t4] – On this stage, the current on the

transformer primary side is the sum of the input current and the one that flows through C2. The secondary circuit

charges C4 through diode D2. This stage ends when S2 turns-on and S1 turns-off.

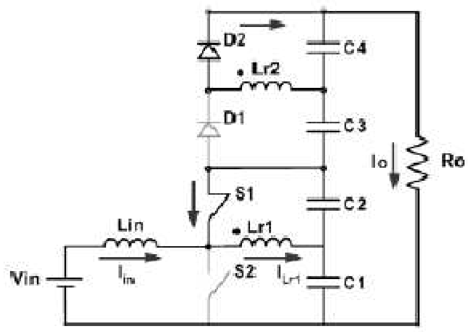

Fig. 8. Fourth Stage.

V. EXPERIMENTAL RESULTS

This section presents the experimental results. The wave forms showed certify the obtained simulation results, as can be seen in figure 4.

The specifications are presented on table I. The choice of large output capacitors was made based on predicting the use of an inverter connected to the converter output, which would require large capacitors in order to attenuate the low frequency ripple.

TABLE I

Converter Specifications

Input Voltage	24 Vdc
Output Voltage	200 Vdc
Nominal Power	500 W
Switching Frequency	50kHz
Transformer turns ratio (n)	3
Inductance of L_{in}	120µH
Capacitances of C_1, C_2, C_3 and C_4	680µF

Figure 9 shows the input and output voltage and current waveforms for the nominal load, 500W. It must be observed that the ripple on the output voltage waveform is inside the 10% range projected.

Experimental tests have shown that an abrupt change on the C1 capacitance value reflect directly on the output voltage ripple. However, with a reduction of C1, the current peak across the switch during its turn-off is also reduced, lowering the related losses.

Figures 10 and 11 present the voltage and current waveforms across S1 and S2, where it can be noticed that those are coherent to the theoretical analysis developed. It can also be observed a voltage peak at the switch turn-on, though this peak is lower than the maximum supported voltage, thus not compromising the converter operation.

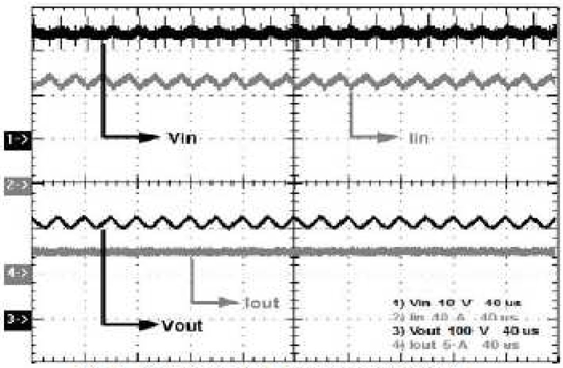

Fig. 9 Input and output voltages and currents

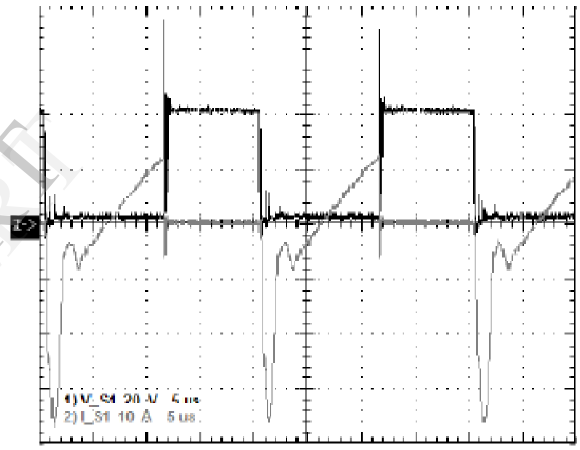

Fig. 10. Voltage and current through S1.

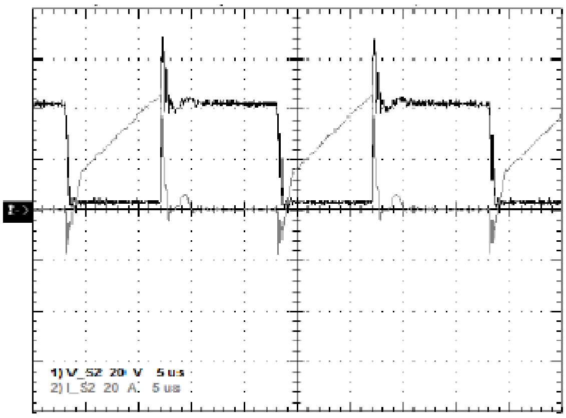

Fig. 11. Voltage and current through S2.

As can be observed in Figure 12, there is no overvoltage across the diodes D1 and D2.

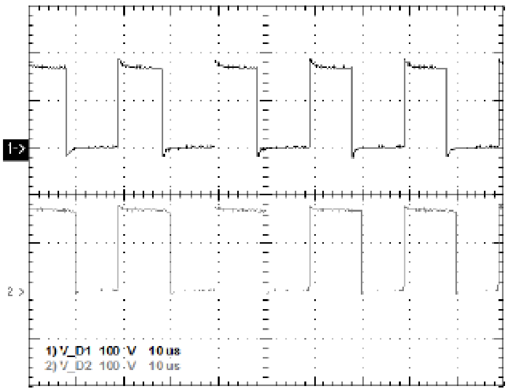

Fig. 12. Voltage through D1 and D2.

From Figure 13 it can be observed the voltage and current waveforms across the primary side of the transformer, where no DC level can be noticed.

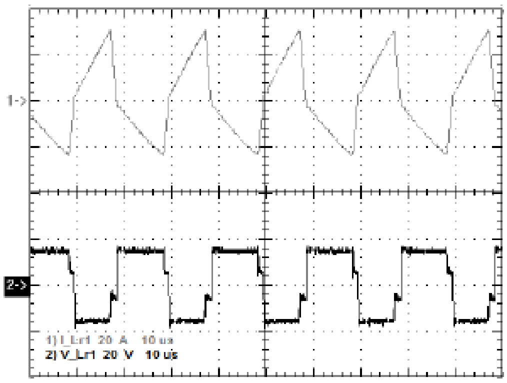

Fig. 13. Voltage and current through Lr.

Figure 14 presents the voltage across each output capacitor, which are equilibrated. Measured VC1 is 25V, while VC2 is 18.1V, VC3 is 90V, and VC4 is 74.2V. With a transformer relation of 1:3, it is expected that the voltage across C3 should be three times the voltage across C1, and the same relation between C2 and C4.

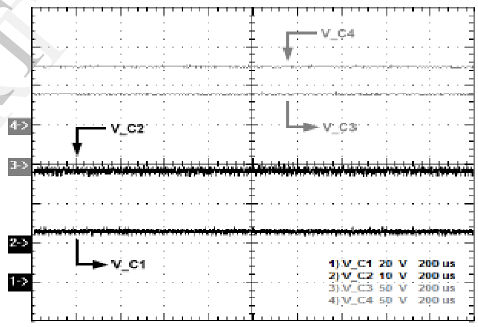

Fig. 14. Voltage across C1, C2, C3 and C4.

VI. CONCLUSION

A boost converter with high voltage gain was presented, and its equations, operation principle, and main theoretical waveforms were all detailed. The topology presents, as main feature, a large voltage step-up with reduced voltage stress across the main switches, important when employed in grid connected systems based on battery storage, like renewable energies systems.

Based on the simulation results, the idea of integrating converters in a single stage seems to be promising on the path to obtain additional topologies feasible to photovoltaic and fuel cell applications. Further studies and work on the same is in progress in order to get the experimental results for both the open and close looped operations.

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